3. The temperatures 100° C and 212° F are identical.

In some scientific and engineering work, particularly where heat calculations are involved, an absolute temperature scale is used. The zero point on an absolute temperature scale is the point called absolute zero. Absolute zero is determined theoretically, rather than by actual measurement. Since the pressure of a gas at constant volume is directly proportional to the temperature, it is logical to assume that the pressure of a gas is a valid measure of its temperature. On this assumption, the lowest possible temperature (absolute zero) is defined as the temperature at which the pressure of a gas would be zero.

Two absolute temperature scales have been in use for many years. The rankine absolute scale is an extension of the Fahrenheit scale; it is sometimes called the Fahrenheit absolute scale. Degrees on the Rankine scale are the same size as degrees on the Fahrenheit scale, but the zero point on the Rankine scale is at -459.67° Fahrenheit. In other words, absolute zero is zero on the Rankine scale and -459.67 degrees on the Fahrenheit scale.

A second absolute scale, the kelvin, is more widely used than the Rankine. The Kelvin scale was originally conceived as an extension of the Celsius scale, with degrees of the same size but with the zero point shifted to absolute zero. Absolute zero on the Celsius scale is -273.15° C.

In 1954, a new international absolute scale was developed. The new scale was based upon one fixed point, rather than two. The one fixed point was the triple point of water--that is, the point at which all three phases of water (solid, liquid, and vapor) can exist together in equilibrium. The triple point of water, which is 0.01° C above the freezing point of water, was chosen because it can be reproduced with much greater accuracy than either the freezing point or the boiling point. On this new scale, the triple point was given the value 273.16 K. Note that neither the word "degrees" nor the symbol ° is used; instead, the unit is called a "kelvin" and the symbol is K rather than ° K.

In 1960, when the triple point of water was finally adopted as the fundamental reference for this temperature scale, the scale was given the nameof International Practical Temperature Scale. However, you will often see this scale referred to as the Kelvin scale.

Although the triple point of water is considered the basic or fundamental reference for the International Practical Temperature Scale, five other fixed points are used to help define the scale. These are the freezing point of gold, the freezing point of silver, the boiling point of sulfur, the boiling point of water, and the boiling point of oxygen.

Figure 7-1 is a comparison of the Kelvin (International-Practical), Celsius, Fahrenheit, and Rankine (Fahrenheit-Absolute) temperature scales. All of the temperature points listed above absolute zero are considered as fixed points on the Kelvin scale except for the freezing point of water. The other scales, as previously mentioned, are based on the freezing and boiling points of water.

TEMPERATURE MEASURING DEVICES

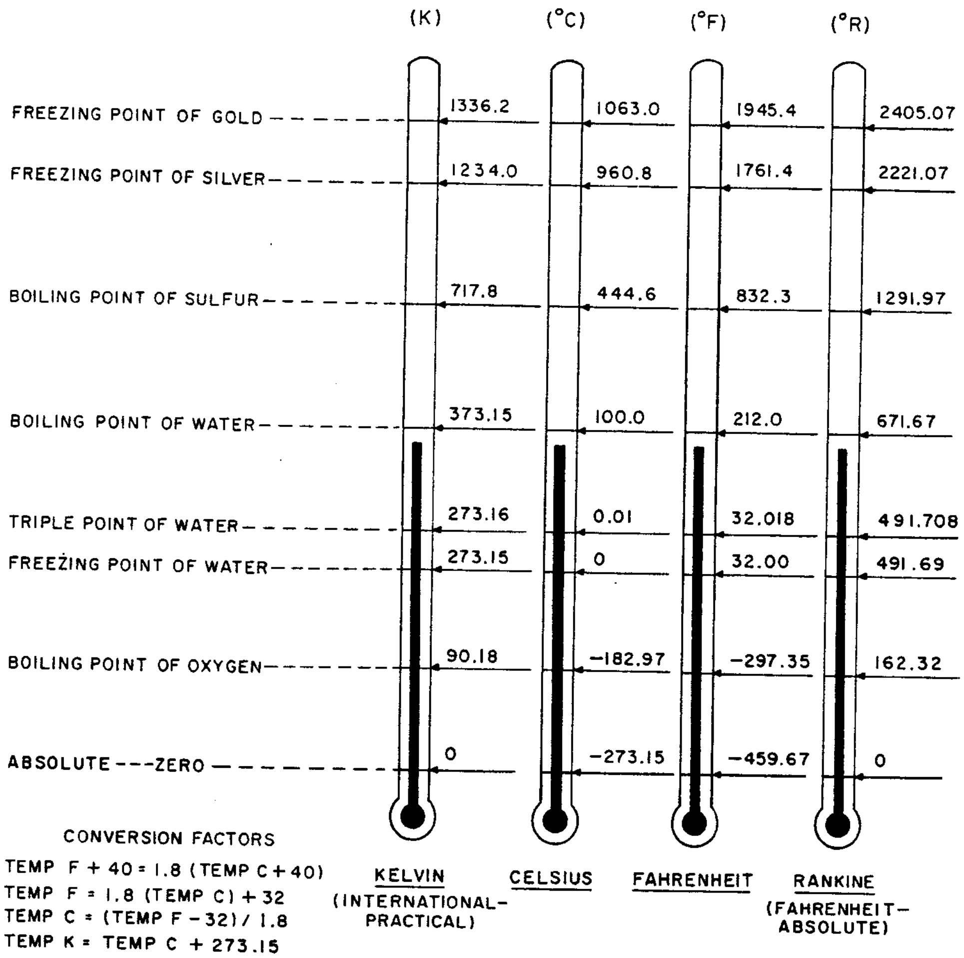
Since temperature is one of the basic engineering variables, temperature measurement is essential to the proper operation of a shipboard engineering plant. The temperature of steam, water, fuel oil, lubricating oil, and other vital fluids must be measured at frequent intervals and the results of this measurement must in many cases be entered in engineering records and logs.

Devices used for measuring temperature may be classified in various ways. In this discussion we will consider the two major categories of (1) expansion thermometers, and (2) pyrometers.

Expansion Thermometers

Expansion thermometers operate on the principle that the expansion of solids, liquids, and gases has a known relationship to temperature changes. The types of expansion thermometers discussed here are (1) liquid-in-glass thermometers, (2) bimetallic expansion thermometers, and (3) filled-system expansion thermometers.

LIQUID-IN-GLASS THERMOMETERS.—Liquid-in-glass thermometers are probably the oldest, the simplest, and the most widely used devices for measuring temperature. A liquid-in-glass thermometer (fig. 7-2) consists of a bulb and a very fine bore capillary tube containing mercury, mercury-thallium, alcohol, toluol, or some other liquid which expands uniformly as the temperature rises and contracts uniformly as the temperature falls. The selection of liquid is based on the temperature



33.11(147B)

Figure 7-1.—Comparison of Kelvin, Celsius, Fahrenheit, and Rankine temperature.

range in which the thermometer is to be used. Mercury (or mercury-thallium) is commonly used because it is a liquid over a wide range of temperatures (—60° to 1200° F) and because it has a nearly constant coefficient of expansion.[5]

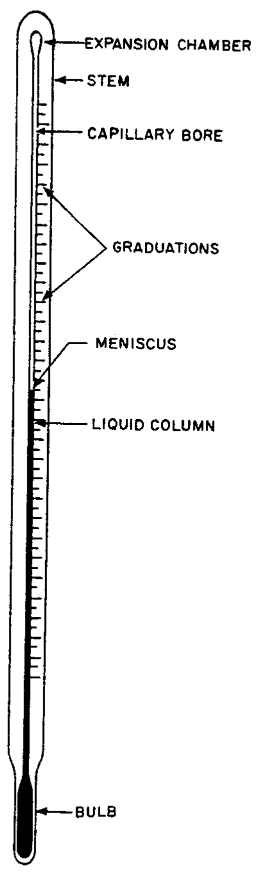
Almost all liquid-in-glass thermometers are sealed so that atmospheric pressure will not affect the reading. The space above the liquid in this type of thermometer may be a vacuum or it may be filled with an inert gas such as nitrogen, argon, or carbon dioxide.

The capillary bore may be either round or elliptical. In any case, it is very small so that a relatively small expansion or contraction of the liquid will cause a relatively large change in the position of the liquid in the capillary tube. Although the capillary bore itself is very small in diameter, the walls of the capillary tube are quite thick. Most liquid-in-glass thermometers are made with an expansion chamber at the top of the bore to provide a margin of safety for the instrument if it should accidentally be overheated.

[5]Not all liquids are suitable for use in thermometers. Water, for example, would be an almost impossible choice as a thermometric liquid at ordinary temperatures because its coefficient of expansion varies enormously at temperatures near 0° C. In the temperature range between 0° C and 4° C, water expands when cooled and contracts when heated; thus it actually has a negative coefficient of expansion in this range.

Liquid-in-glass thermometers may have graduations etched directly on the glass stem or the graduations may be carried on a separate strip of material which is placed behind the stem. Many thermometers used in shipboard engineering plants have the graduations marked on a separate strip, since this type is in general easier to read than the type which has the graduations marked directly on the stem.

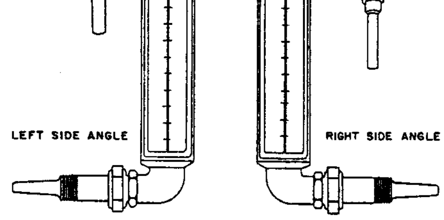
Liquid-in-glass thermometers are made in various designs. The stem may be straight or it may be angled in various ways, depending upon the requirements of service. The thermometers may be armored or they may be partially enclosed by a metal case, if such protection is necessary. Several types of angle-stem liquid-in-glass thermometers of the type commonly used aboard ship are shown in figure 7-3. These thermometers are used in 5-inch, 7-inch, and 9-inch scale lengths. However, bimetallic thermometers are currently being substituted aboard ship for the 5-inch scale liquid-in-glass thermometers.



33.11(147A)
Figure 7-2.—Liquid-in-glass thermometer.

Most liquid-in-glass thermometers used aboard ship are provided with wells or separable sockets. The well is installed in the piping system or equipment where the temperature is to be measured, and the thermometer glass bulb and part of the glass stem are fitted into a thin metal protection tube, packed with a heat-transfer material, and fastened in place in the well. The well is made of metals that will withstand the temperatures, pressures, and fluid velocities without damage; it protects the glass sensing bulb against damage and also eliminates the need for closing down a system or securing a piece of machinery merely in order to replace a thermometer.

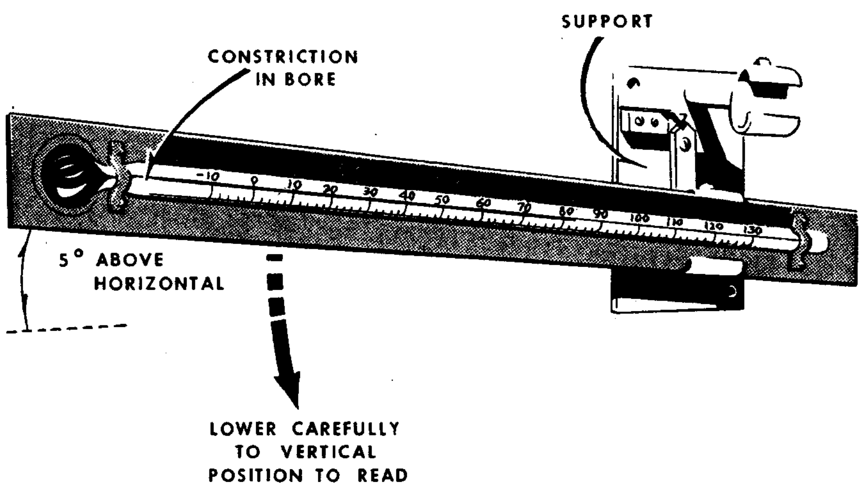
One disadvantage of the well type of installation is that a certain amount of time is required for the thermometer to reach thermal equilibrium with the system in which the temperature is being measured. To some extent, the time lag can be decreased by filling the space around the bulb in the well with a heat transfer medium such as graphite. Where rapid response to temperature changes is a vital requirement, however, bare bulb thermometers are used instead of the well type of installation. Bare bulb thermometers have very much faster response to changes in temperature, but they cannot be removed for replacement or servicing while the machinery is operating or the line is under pressure.



61.26
Figure 7-3.—Angle-stem liquid-in-glass thermometers.

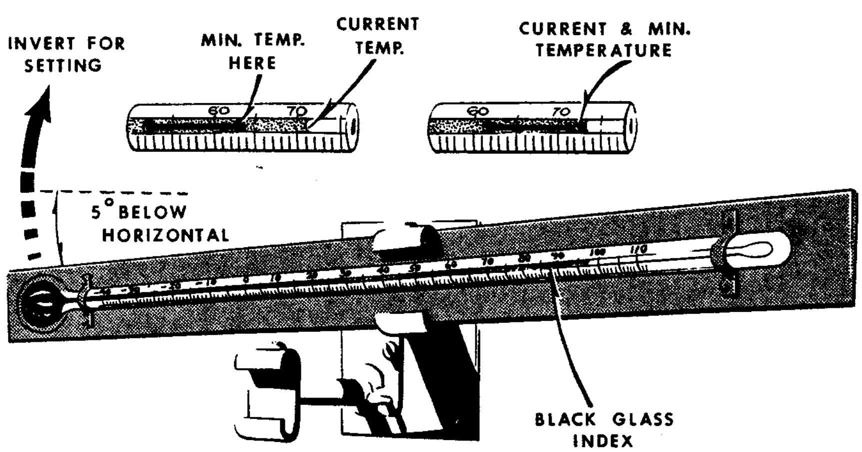
Where special requirements exist, special types of liquid-in-glass thermometers are used. For example, maximum and minimum indicating thermometers are used in magazines aboard ship, for weather observations, and for various other applications where it is necessary to know the highest and the lowest temperatures that have occurred during a certain interval of time. One type of maximum indicating thermometer is shown in figure 7-4, and one type of minimum indicating thermometer is shown in figure 7-5.

The maximum indicating thermometer shown in figure 7-4 is a mercury thermometer with a special constriction in the bore. When the temperature rises, the pressure of the expanding mercury in the bulb forces mercury past the constriction in the bore. When the temperature falls, the mercury does not return to the bulb. Why? Even if the thermometer were in an upright position, the constriction in the bore would prevent the normal return flow of mercury by gravity; in addition, the maximum indicating thermometer is mounted with the bulb a few degrees above the horizontal position, so that the mercury column slopes downward from the constriction. Thus the thermometer always indicates the highest temperature that has been reached since the instrument was last set. Expansion and contraction of the mercury in the bore above the constriction does occur with temperature changes, but it is so slight as to



5.65A

Figure 7-4.—Maximum indicating thermometer.



5.65B

Figure 7-5.—Minimum indicating thermometer.

be negligible for most purposes because only a very small amount of mercury is contained in the very narrow bore.

The minimum indicating thermometer shown in figure 7-5 is an alcohol-in-glass thermometer with an unusually large bore. The upper part of the bore is filled with air under pressure to help prevent evaporation of the alcohol. The thermometer is mounted with the bulb a few degrees below the horizontal position. A dumbbell-shaped piece of black glass (called an index) is the device that makes possible a reading of the minimum temperature that has occurred since the thermometer was last set. As the temperature increases, the alcohol readily flows upward past the index without moving it. As the temperature decreases, the retreating alcohol column flows past the index until the top of the column touches the upper end of the index. With a further decrease in temperature, the alcohol retreats still more and surface tension causes the index to be carried along down with the column. If the temperature increases again, the index is left undisturbed at its lowest point while the alcohol column rises again. Thus the top of the index always indicates the lowest temperature that has occurred since the thermometer was last set.

BIMETALLIC EXPANSION THERMOMETER.—Bimetallic expansion thermometers make use of the fact that different metals have different coefficients of linear expansion.[6] The essential element in a bimetallic expansion thermometer is a bimetallic strip consisting of two layers of different metals fused together. When such a strip is subjected to temperature changes, one layer expands or contracts more than the other, thus tending to change the curvature of the strip.

The basic principle of a bimetallic expansion thermometer is illustrated in figure 7-6. When one end of a straight bimetallic strip is fixed in place, the other end tends to curve away from the side that has the greater coefficient of linear expansion when the strip is heated.

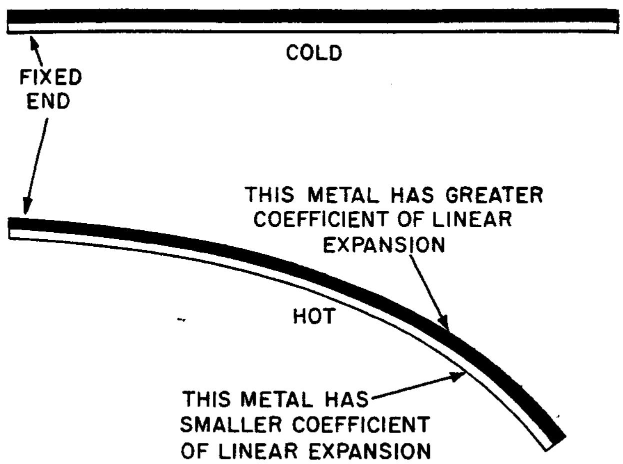


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Figure 7-6.—Effect of unequal expansion of bimetallic strip.

For use in thermometers, the bimetallic strip is normally wound into a flat spiral (fig. 7-7), a single helix, or a multiple helix. The end of the strip that is not fixed in position is fastened to the end of a pointer which moves over a circular scale. Bimetallic thermometers are easily adapted for use as recording thermometers; a pen is attached to the pointer and is positioned in such a way that it marks on a revolving chart.

Bimetallic thermometers used aboard ship are normally used in thermometer wells. The wells are interchangeable with those used for mercury-in-glass thermometers.

FILLED-SYSTEM THERMOMETERS.—In general, filled-system thermometers are designed for use in locations where the indicating part of the instrument must be placed some distance away from the point where the temperature is to be measured.[7] For this reason they are often called distant-reading thermometers.

A filled-system thermometer (fig. 7-8) consists essentially of a hollow metal sensing bulb

[6] The coefficient of linear expansion is defined as the change in length per unit length per degree change in temperature. As is apparent from this definition, the numerical value of the coefficient of linear expansion is independent of the units in which the length is expressed but is not independent of the temperature scale chosen.

[7] This is not true of all filled-system thermometers. In a few designs the capillary tubing is extremely short and in a few it is nonexistent. In general, however, filled-system thermometers are designed to be distant-reading thermometers, and most of them do in fact serve this purpose. Some distant-reading thermometers may have capillaries as long as 125 feet.

at one end of a small-bore capillary tube, connected at the other end to a Bourdon tube or other device which responds to volume changes or to pressure changes. The system is partially or completely filled with a fluid which expands when heated and contracts when cooled. The fluid may be a gas, mercury, an organic liquid, or a combination of liquid and vapor.

The device usually used to indicate temperature changes by its response to volume changes or to pressure changes is called a Bourdon tube.[8] A Bourdon tube is a curved or twisted tube which is open at one end and sealed at the other. The open end of the tube is fixed in position and the sealed end is free to move. The tube is more or less elliptical in cross section; it does not form a true circle. The cross section of a noncircular tube which is sealed at one end tends to become more circular when there is an increase in the volume or in the internal pressure of the contained fluid, and this tends to straighten the tube. Opposing this action, the spring action of the tube metal tends to coil the tube.[9] Since the open end of the Bourdon tube is rigidly fastened, the sealed end moves as the volume or pressure of the contained fluid changes. When a pointer is attached to the sealed end of the tube through appropriate linkages, and when the assembly is placed over an appropriately calibrated dial, the result is a Bourdon-tube gage that may be used for measuring temperature or pressure, depending upon the design of the gage and the calibration of the scale.

Bourdon tubes are made in several shapes for various applications. The C-shaped Bourdon tube shown in figure 7-9 is perhaps the most commonly used type; spiral and helical Bourdon tubes are used where design requirements include the need for a longer length of Bourdon tube.

There are two basic types of filled-system thermometers: those in which the Bourdon tube responds primarily to changes in the volume of the filling fluid and those in which the Bourdon tube responds primarily to changes in the pressure of the filling fluid. Obviously, there is always some pressure effect in volumetric thermometers and some volumetric effect in

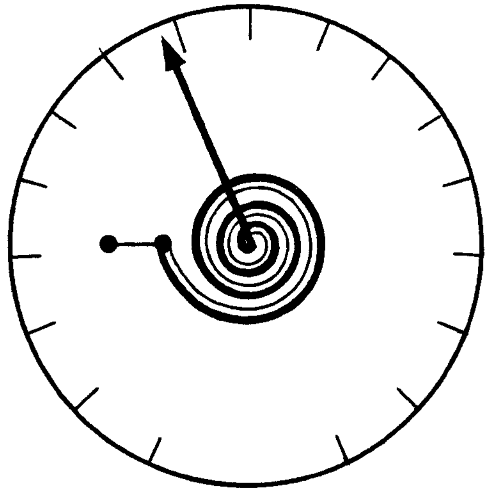

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Figure 7-7.—Bimetallic thermometer (flat spiral element).

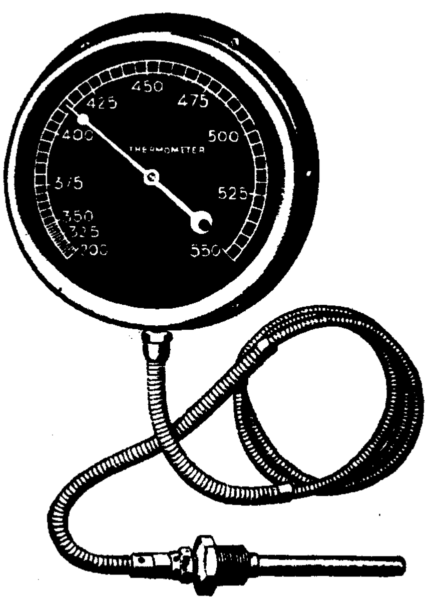

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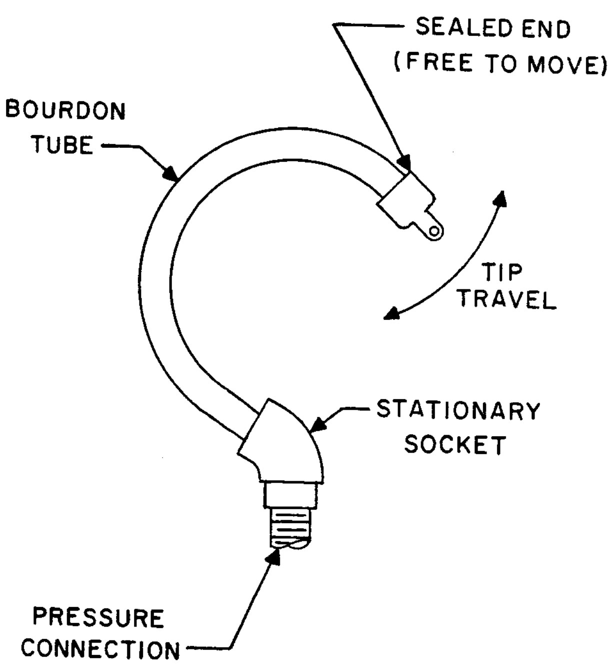
Figure 7-8.—Distant-reading Bourdon-tube thermometer.

[8]Bourdon tubes are sometimes called Bourdon springs, Bourdon elements, or simply Bourdons. Other devices such as bellows or diaphragms are used in some filled-system thermometers, but they are by no means as common as the Bourdon tube for this application.

[9]The precise nature of Bourdon-tube movement with pressure and volume changes is extremely complex and not completely describable in purely analytical terms. Bourdon-tube instruments are designed for specific applications on the basis of a series of empirical observations and tests.



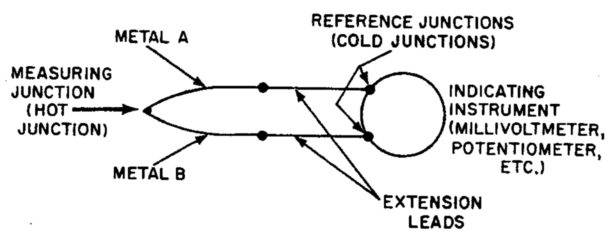
38.211(147B)
Figure 7-9.—C-shaped Bourdon tube.

pressure thermometers; the distinction deals with the major response of the Bourdon tube.

Pyrometers

The term pyrometer is used to include a number of temperature measuring devices which, in general, are suitable for use at relatively high temperatures; some pyrometers, however, are also suitable for use at low temperatures. The types of pyrometers we are concerned with here include thermocouple pyrometers, resistance thermometers, radiation pyrometers, and optical pyrometers.

THERMOCOUPLE PYROMETERS.—The operation of a thermocouple pyrometer (sometimes called a thermoelectric pyrometer) is based on the observed fact that an electromotive force (emf)[10] is generated when the two junctions of two dissimilar metals are at different temperatures. A simple thermocouple is illustrated in figure 7-10. Since the electromotive force generated is proportional to the temperature difference between the measuring junction (hot junction) and the reference junctions (cold junctions), the indicating instrument can be marked off to indicate degrees of temperature even though it is actually measuring emf's. The indicating instrument is a millivoltmeter or some other electrical device capable of measuring and indicating small direct-current emf's. The strips or wires of dissimilar metals are welded, twisted, fused, or otherwise firmly joined together. The extension leads are usually of the same metals as the thermocouple itself.



147.55
Figure 7-10.—Simple thermocouple.

RESISTANCE THERMOMETERS.—Resistance thermometers are based on the principle that the electrical resistance of a metal changes with changes in temperature. A resistance thermometer is thus actually an instrument which measures electrical resistance but which is calibrated in degrees of temperature rather than in units of electrical resistance.

The sensitive element in a resistance thermometer is a winding of small diameter nickel, platinum, or other metallic wire. The resistance winding is located in the lower end of a bulb (sometimes called a stem); it is electrically but not thermally insulated from the stem. The resistance winding is connected by two, three, or four leads to the circuit of the indicating instrument. The circuit is a Wheatstone bridge or some other simple circuit which contains known resistances with which the resistance of the thermometer winding is compared.

RADIATION AND OPTICAL PYROMETERS.—Radiation and optical pyrometers are used to measure very high temperatures. Both types of pyrometers measure temperature by measuring the amount of energy radiated by the hot object. The main difference between the two types is in their range of sensitivity; radiation pyrometers are (theoretically, at least) sensitive to the

[10] Basic information on electricity is given in chapter 20 of this text.

entire spectrum of radiant energy, while optical pyrometers are sensitive to only one wavelength or to a very narrow band of wavelengths.

Figure 7-11 illustrates schematically the general operating principle of a simple radiation pyrometer. Radiant energy from the hot object is concentrated on the detecting device by means of a lens or, in some cases, a conical mirror or a combination of mirror and lens. The detecting device may be a thermocouple, a thermopile (that is, a group of thermocouples in series), a photocell, or some other element in which some electrical quantity (emf, resistance, etc.) varies as the temperature of the hot object varies. The meter or indicated part of the instrument may be a millivoltmeter or some similar device.

An optical pyrometer measures temperature by comparing visible light emitted by the hot object with light from a standard source. A common type of optical pyrometer is shown in figure 7-12. This instrument consists of an eyepiece, a telescope which contains a filament similar to the filament of an electric light bulb and a potentiometer.

The person operating the optical pyrometer looks through the eyepiece and focuses the telescope on the hot object, meanwhile also observing the tin glowing filament across the field of the telescope. While watching the hot object and the filament, the operator adjusts the filament current (and consequently the brightness of the filament) by turning a knob on the potentiometer until the filament seems to disappear and to merge with the hot object. When the filament current has been adjusted so that the filament just matches the hot object in brightness, the operator turns another knob slightly to balance the potentiometer. The potentiometer measures filament current but the dial is calibrated in degrees of temperature. As may be noted from this description, this type of optical pyrometer requires a certain amount of skill and judgment on the part of the operator. In some other types of optical pyrometers, automatic operation is achieved by use of photoelectric cells arranged in a bridge network.

MEASUREMENT OF PRESSURE

Pressure, like temperature, is one of the basic engineering variables and one that must frequently be measured aboard ship. Before taking up the devices used to measure pressure, let us consider certain definitions that are important in any discussion of pressure measurement.

PRESSURE DEFINITIONS

Pressure is defined as force per unit area.

The simplest pressure units are ones that indicate how much force is applied to an area of a certain size. These units include pounds per square inch, pounds per square feet, ounces per square inch, newtons per square millimeter, and dynes per square centimeter, depending upon the system being used.

You will also find another kind of pressure unit, and this type appears to involve length. These units include inches of water, inches of mercury (Hg), and inches of some other liquid of known density. Actually, these units do not involve length as a fundamental dimension. Rather, length is taken as a measure of force or weight. For example, a reading of 1 inch of water (1 in. H_2O) means that the exerted pressure is able to support a column of water 1 inch

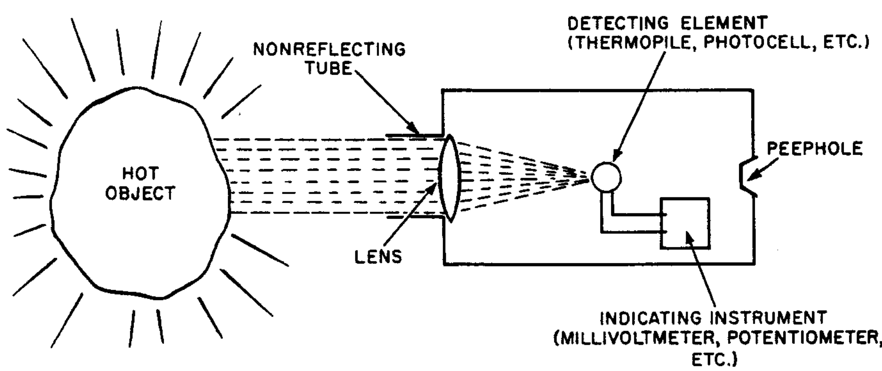


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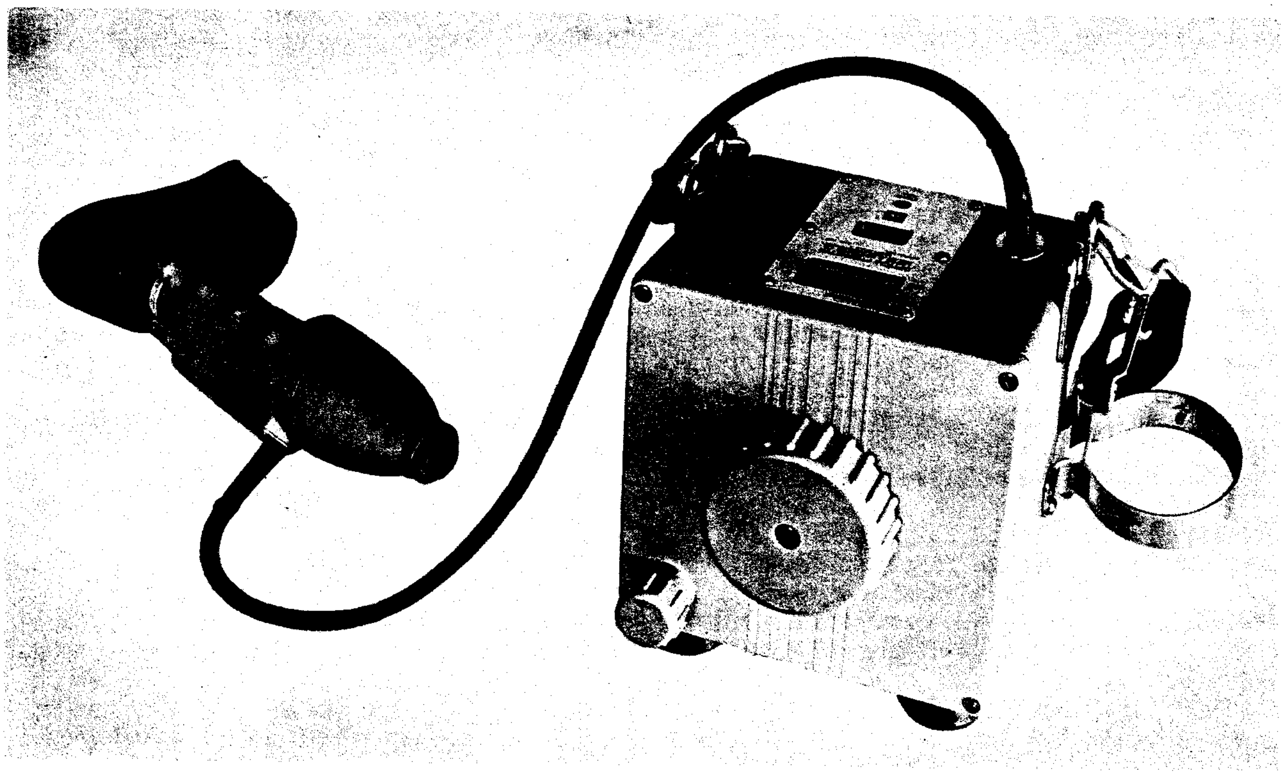
Figure 7-11.—Simple radiation pyrometer.



102.20X

Figure 7-12.—Optical pyrometer.

high, or that a column of water in a U-tube would be displaced 1 inch by the pressure being measured. Similarly, a reading of 12 inches of mercury (12 in. Hg) means that the measured pressure is sufficient to support a column of mercury 12 inches high. What is really being expressed (even though it is not mentioned in the pressure unit) is the fact that a certain quantity of material (water, mercury, etc.) of known density will exert a certain definite force upon a specified area. Pressure is still force per unit area, even if the pressure unit refers to inches of some liquid.

It is often necessary to convert from one type of pressure unit to another. Complete conversion tables may be found in many texts and handbooks. Conversion factors for pounds per square inch, inches of mercury, and inches of water are:

1 in. Hg = 0.49 psi
1 psi = 2.036 in. Hg

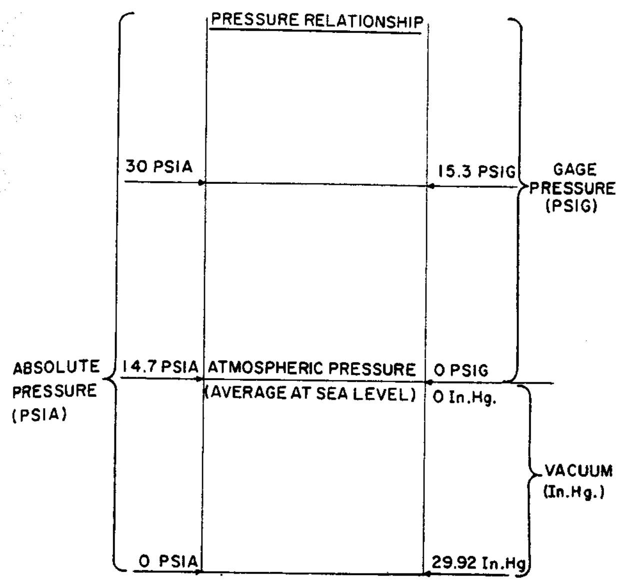
1 in. H_2O = 0.036 psi
1 psi = 27.68 in. H_2O

1 in. H_2O = 0.074 in. Hg
1 in. Hg = 13.6 in. H_2O

In interpreting pressure measurements, a great deal of confusion arises because the zero point on most pressure gages represents atmospheric pressure rather than zero absolute pressure. Thus it is often necessary to specify the kind of pressure being measured under any given conditions. To clarify the numerous meanings of the word pressure, the relationships among gage pressure, atmospheric pressure, vacuum, and absolute pressure, is illustrated in figure 7-13.

Gage Pressure is the pressure actually shown on the dial of a gage that registers pressure at or above atmospheric pressure. An ordinary pressure gage reading of zero does not mean that there is no pressure in the absolute sense; rather, it means that there is no pressure in excess of atmospheric pressure.

Atmospheric pressure is the pressure exerted by the weight of the atmosphere. At sea level, the average pressure of the atmosphere is



147.181

Figure 7-13.—Relationships among gage pressure, atmospheric pressure, vacuum, and absolute pressure.

sufficient to hold a column of mercury at the height of 76.0 millimeters or 29.92 inches of mercury. Since a column of mercury 1 inch high exerts a pressure of 0.49 pound per square inch, a column of mercury 29.92 inches high exerts a pressure that is equal to 29.92 x 0.49, or approximately 14.7 psi. Since we are dealing now in absolute pressure, we say that the average atmospheric pressure at sea level is 14.7 pounds per square inch absolute. It is zero on the ordinary pressure gage.

Notice, however, that the figure of 14.7 pounds per square inch absolute (psia) represents the average atmospheric pressure at sea level, and does not always represent the actual pressure being exerted by the atmosphere at the moment that a gage is being read.

Barometric pressure is the term used to describe the actual atmospheric pressure that exists at any given moment. Barometric pressure may be measured by a simple mercury column or by a specially designed instrument called an aneroid barometer.

A space in which the pressure is less than atmospheric pressure is said to be under vacuum. The amount of vacuum is expressed in terms of the difference between the absolute pressure in the space and the pressure of the atmosphere. Most commonly, vacuum is expressed in inches of mercury, with the vacuum gage scale marked from 0 to 30 inches of mercury. When a vacuum gage reads zero, the pressure in the space is the same as atmospheric pressure—or, in other words, there is no vacuum. A vacuum gage reading of 29.92 inches of mercury would indicate a perfect (or nearly perfect) vacuum. In actual practice, it is impossible to obtain a perfect vacuum even under laboratory conditions.

Absolute pressure is atmospheric pressure plus gage pressure or minus vacuum. For example, a gage pressure of 300 psig equals an absolute pressure of 314.7 psia (300 + 14.7). Or, for example, consider a space in which the measured vacuum is 10 inches of mercury vacuum; the absolute pressure in this space must then be 19.92 or approximately 20 inches of mercury absolute. It is important to note that the amount of pressure in a space under vacuum can only be expressed in terms of absolute pressure.

You may have noticed that sometimes we say psig to indicate gage pressure and other times we merely say psi. By common convention, gage pressure is always assumed when pressure is given in pounds per square inch, pounds per square foot, or similar units. The "g" (for gage) is added only when there is some possibility of confusion. Absolute pressure, on the other hand, is always expressed as pounds per square inch absolute (psia), pounds per square foot absolute (psfa), and so forth. It is always necessary to establish clearly just what kind of pressure we are talking about, unless this is very clear from the nature of the discussion.

To this point, we have considered only the most basic and most common units of measurement. It is important to remember that hundreds of other units can be derived from these units, and that specialized fields require specialized units of measurement. Additional units of measurement are introduced in appropriate places throughout the remainder of this training manual. When you encounter more complicated units of measurement, you may find it helpful to review the basic information given here previously.

PRESSURE MEASURING DEVICES

Most pressure measuring devices used aboard ship utilize mechanical pressure elements.[11] There are two major classes of mechanical pressure elements: (1) liquid-column elements, and (2) elastic elements.

Liquid-Column Elements

Liquid-column pressure measuring elements include the devices commonly referred to as barometers and manometers. Liquid-column elements are simple, reliable, and accurate. They are used particularly (although not exclusively) for the measurement of relatively low pressures or small pressure differentials. Liquids commonly used in this type of pressure gage include mercury, water, and alcohol.

One of the simplest kinds of liquid-column elements is the fixed-cistern barometer (fig. 7-14) which is used to measure atmospheric pressure. Mercury is always used as the liquid in this type of instrument. Atmospheric pressure acts upon the open surface of the mercury in the cistern. Since the tube is open at the cistern end, and since there is a vacuum above the mercury in the tube, the height of the mercury in the tube is at all times an indication of the existing atmospheric (barometric) pressure.

A simple U-tube liquid-column element for measuring absolute pressure is shown in figure 7-15. The liquid used in this device is mercury. There is a vacuum above the mercury at the closed end of the tube; the open end of the tube is exposed to the pressure to be measured. The absolute pressure is indicated by the difference in the height of the two mercury columns.

Manometers are available in many different sizes and designs. Some are installed in such a way that the U-tube is readily recognizable, as in part A of figure 7-16; but in some designs the U-tube is inverted or inclined at an angle. The so-called single-tube or straight-tube manometer (part B of fig. 7-16) is actually a U-tube in which only one leg is made of glass.

Elastic Elements

Elastic elements used for pressure measurement include Bourdon tubes, bellows, and diaphragms. All three types of elastic elements are suitable for use in pressure gages, vacuum gages, and compound (both pressure and vacuum) gages. Bourdon-tube elements are suitable for the measurement of very high pressures, up to 100,000 psig. The upper limit for bellows elements is about 800 psig and for diaphragm elements about 400 psig. Diaphragm elements and bellows elements are commonly used for the measurement of very high vacuum (or very low absolute pressure) but Bourdon tubes can be used for such applications.

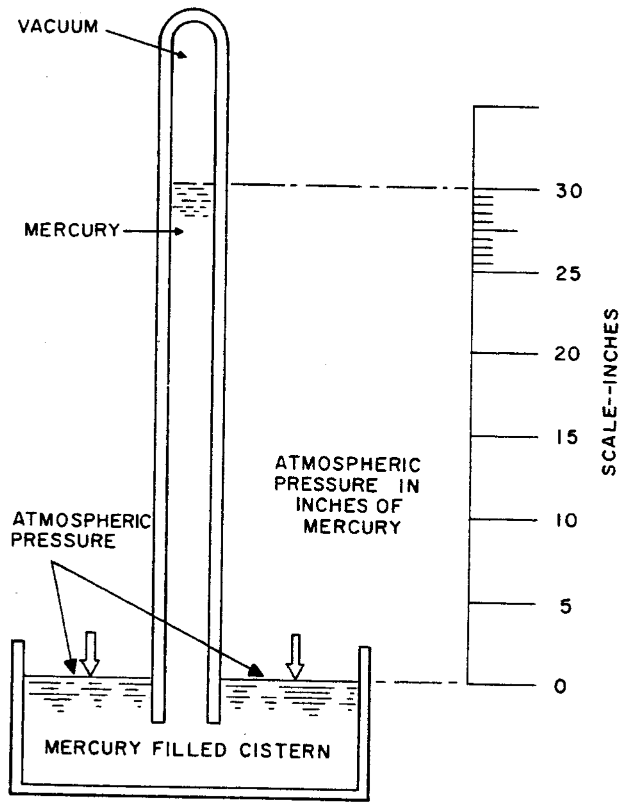


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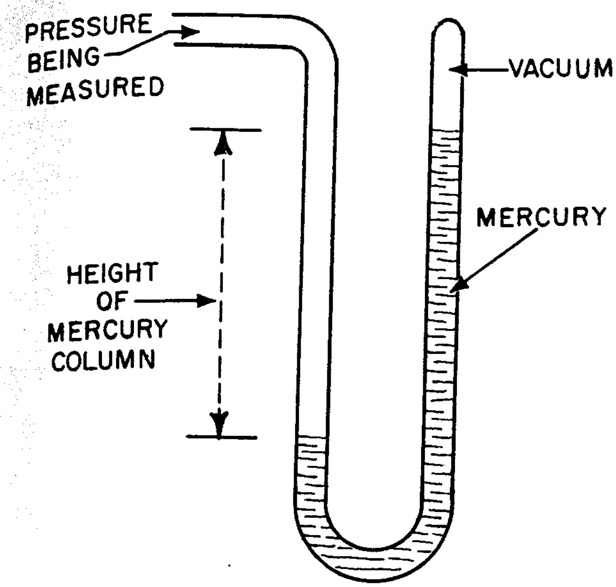
Figure 7-14.—Simple Barometer (fixed cistern) for measuring atmospheric pressure.

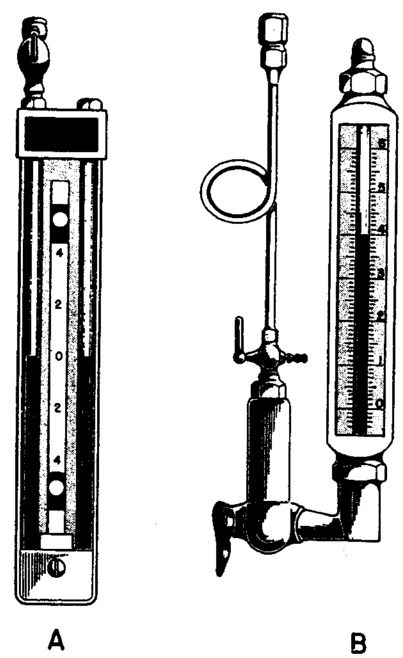
BOURDON-TUBE ELASTIC ELEMENTS.— Bourdon-tube elements used in pressure gages are essentially the same as those described for use in filled-system thermometers. Bourdon tubes for pressure gages are made of brass, phosphor bronze, stainless steel, beryllium-copper, or other metals, depending upon the requirements of service.

Bourdon-tube pressure gages are often classified as simplex or duplex, depending upon whether they measure one pressure or two. A simplex gage such as the one shown in figures

[11] Strain gages and other electrical pressure measuring devices are not included in this discussion; they are rarely used aboard ship.



147.57
Figure 7-15.—U-tube liquid-column element for measuring absolute pressure.

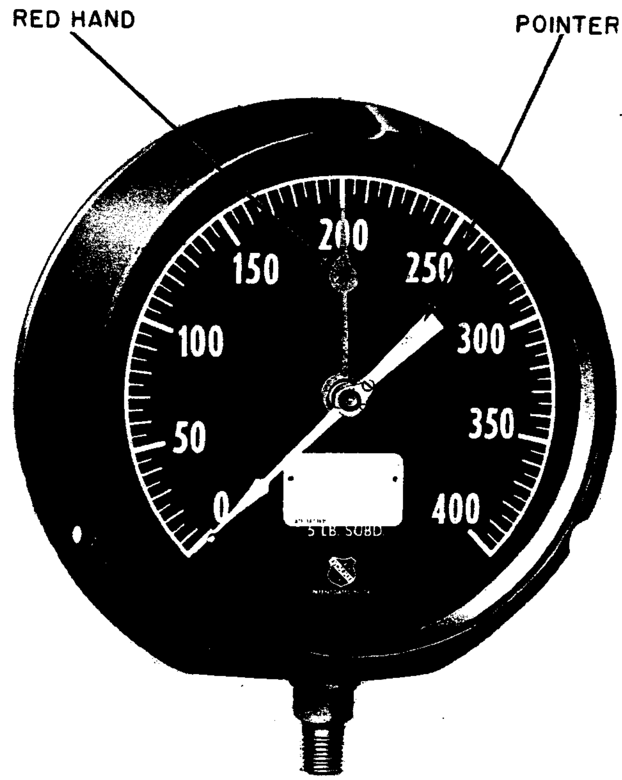


61.4X
Figure 7-16.—Two types of manometers. (A) Standard U-tube. (B) Single-tube.

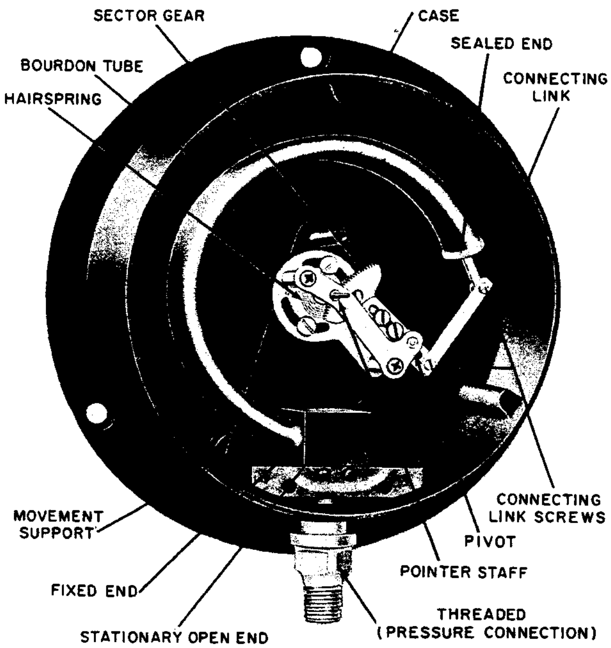
7-17, 7-18, and 7-19 has only one Bourdon tube and measures only one pressure. (The pointer marked RED HAND in figure 7-17 is a manually positioned hand that is set to the normal working pressure of the machinery or equipment on which the gage is installed; the hand marked POINTER is the only hand that moves in response to pressure changes.)

When two Bourdon tubes are mounted in a single case, with each mechanism acting independently but with the two pointers mounted on a common dial, the assembly is called a duplex gage. The dial of a duplex gage is shown in figure 7-20. The two Bourdon tubes and the operating mechanism are shown in figure 7-21, and the gear mechanism is shown in figure 7-22. Note that each Bourdon tube has its own pressure connection and its own pointer. Duplex gages are used to give simultaneous indication of the pressure at two different locations.

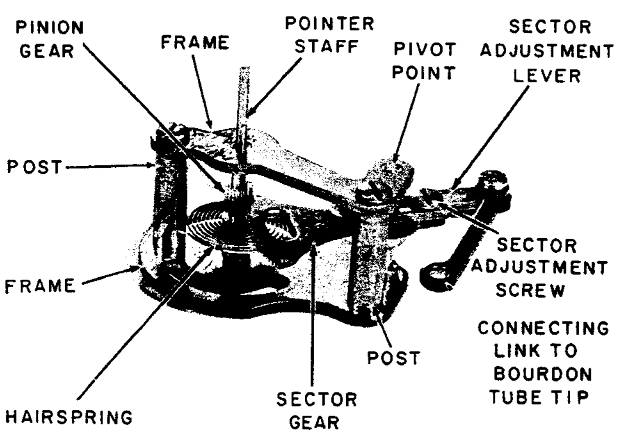
Bourdon-tube vacuum gages are marked off in inches of mercury, as shown in figure 7-23.



38.211BX
Figure 7-17.—Dial of a simplex Bourdon-tube pressure gage.

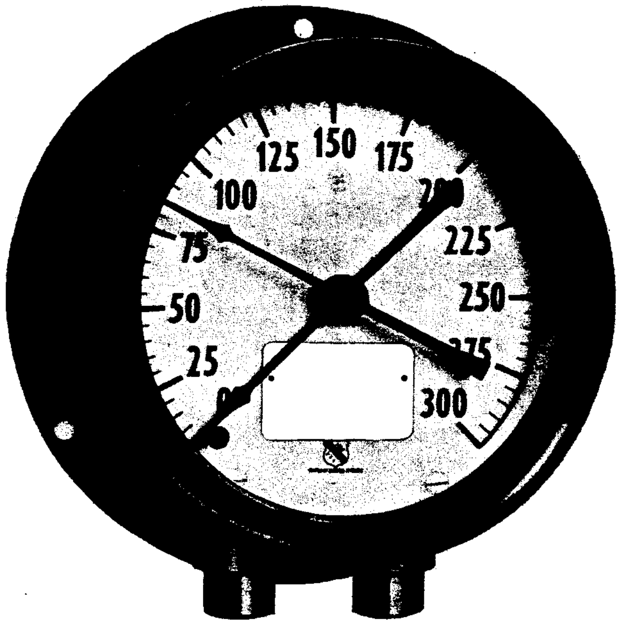


38.211AX
Figure 7-18.—Operating mechanism of simplex Bourdon-tube pressure gage.

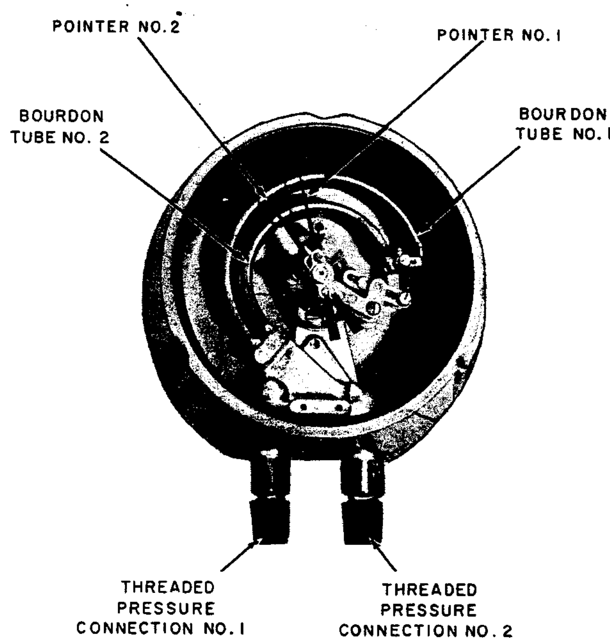


38.211C
Figure 7-19.—Gear mechanism of simplex Bourdon-tube pressure gage

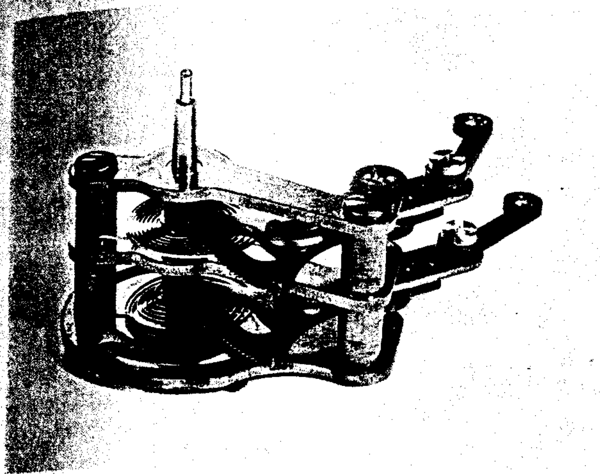
When a gage is designed to measure both vacuum and pressure, it is called a compound gage and is marked off both in inches of mercury and in psig, as shown in figure 7-24.



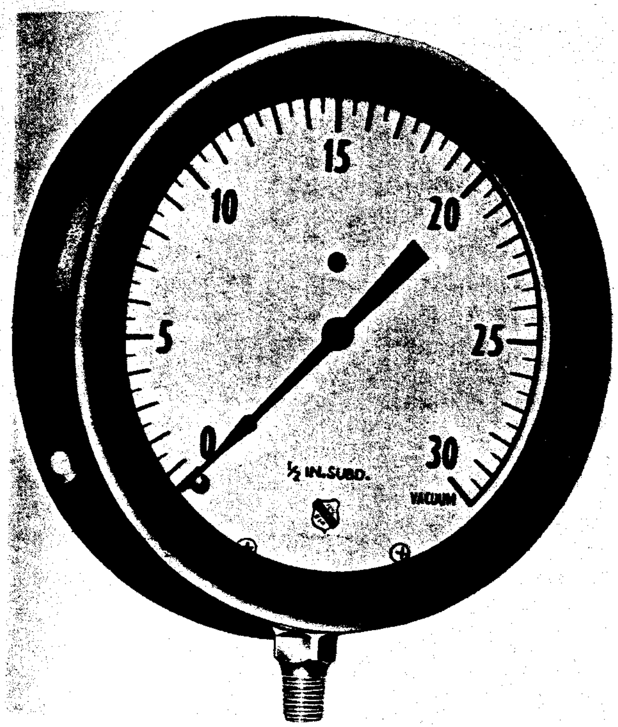
38.211FX
Figure 7-20.—Dial of a duplex Bourdon-tube pressure gage.



38.211G
Figure 7-21.—Two Bourdon tubes and operating mechanism of duplex Bourdon-tube pressure gage.

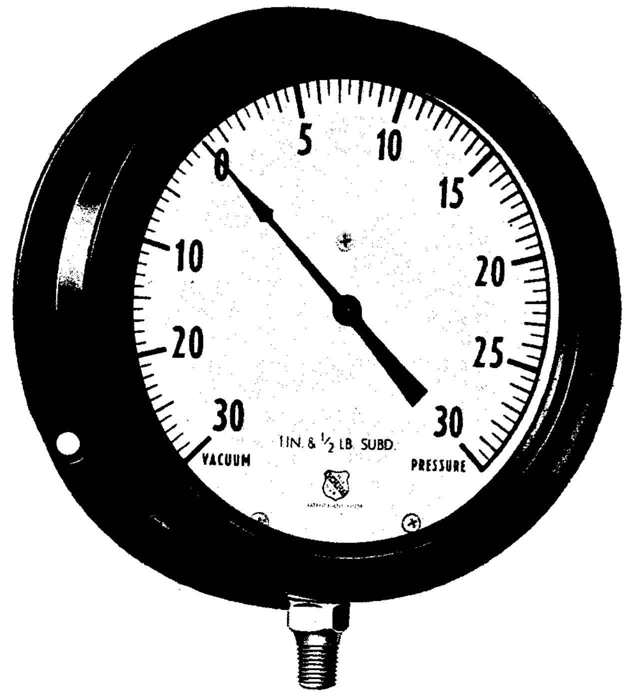


38.211CA
Figure 7-22.—Gear mechanism of duplex Bourdon-tube pressure gage.



38.211DX
Figure 7-23.—Bourdon-tube vacuum gage.

Differential pressure may also be measured with Bourdon-tube gages. One kind of Bourdon-tube differential pressure gage is shown in figure 7-25. This gage has two Bourdon tubes

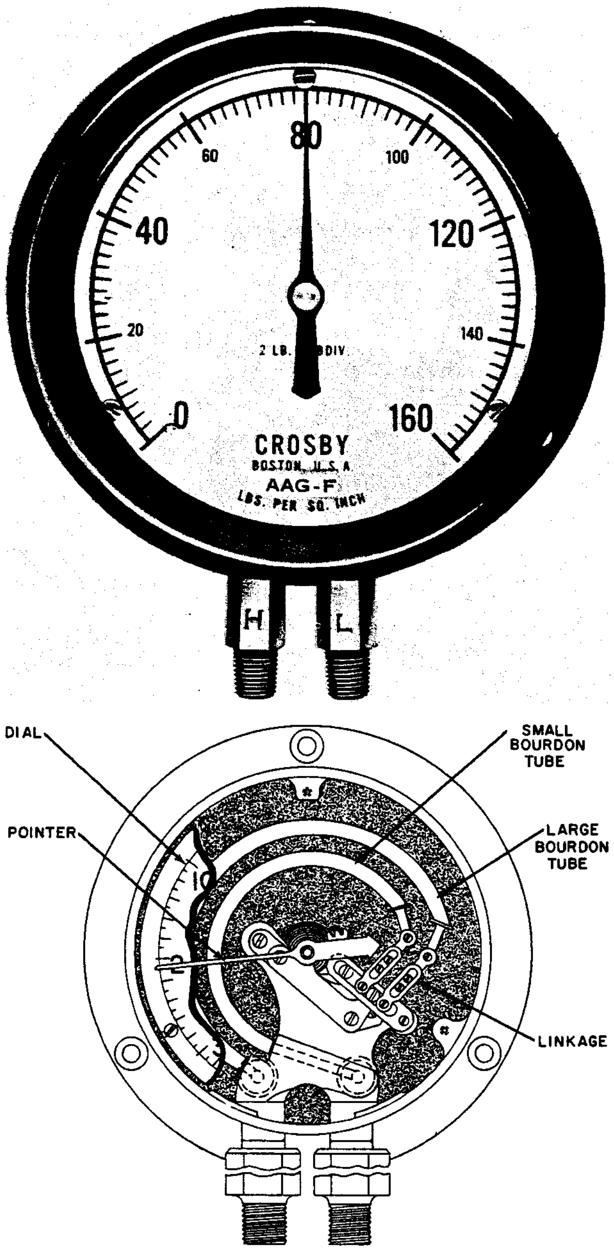


38.211EX
Figure 7-24.—Compound Bourdon-tube gage.

but only one pointer. The Bourdon tubes are connected in such a way that it is the pressure difference, rather than either of the two actual pressures, that is indicated by the pointer.

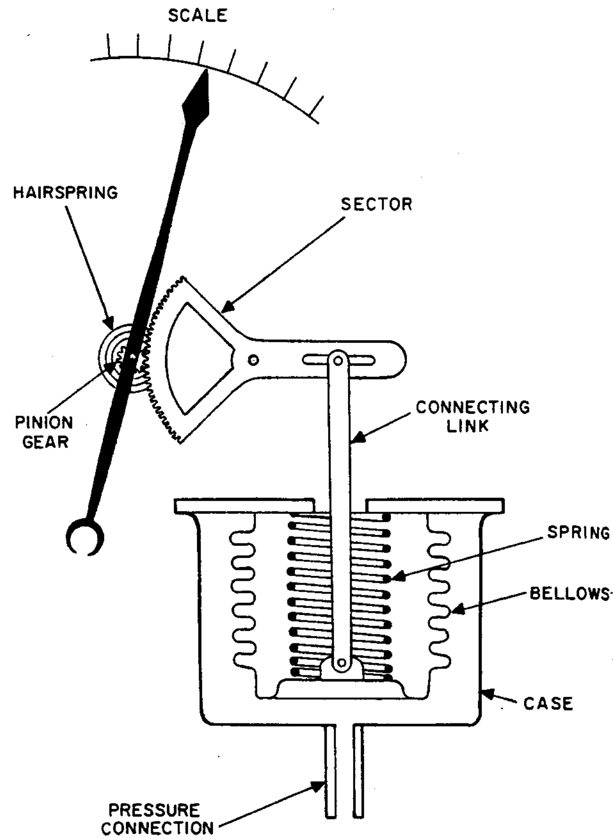
BELLOWS ELASTIC ELEMENTS.—A bellows elastic element is a convoluted unit that expands and contracts axially with changes in pressure. The pressure to be measured can be applied to the outside or to the inside of the bellows; in practice, most bellows-type measuring devices have the pressure applied to the outside of the bellows, as shown in figure 7-26. Bellows elastic elements are made of brass, phosphor bronze, stainless steel, beryllium-copper, or other metal suitable for the intended service of the gage.

Most bellows-type gages are spring-loaded—that is, a spring opposes the bellows and thus prevents full expansion of the bellows. Limiting the expansion of the bellows in this way protects the bellows and prolongs its life. In a spring-loaded bellows-type element, the deflection is the resultant of the force acting on the bellows and the opposing force of the spring.



38.211KX
Figure 7-25.—Bourdon-tube differential pressure gage.

Although some bellows-type instruments can be designed for measuring pressures up to 800 psig, their primary application aboard ship is in the measurement of quite low pressures or small pressure differentials. For example, bellows elements are widely used in boiler control systems[12] because the air pressures of the control systems are generally very low.



61.3(147B)A
Figure 7-26.—Simple bellows gage.

Many differential pressure gages are of the bellows type. In some designs, one pressure is applied to the inside of the bellows and the other pressure is applied to the outside. In other designs, a differential pressure reading is obtained by opposing two bellows in a single case.

Bellows elements are used in various applications where the pressure-sensitive device must be powerful enough to operate not only the indicating pointer but also some type of recording device.

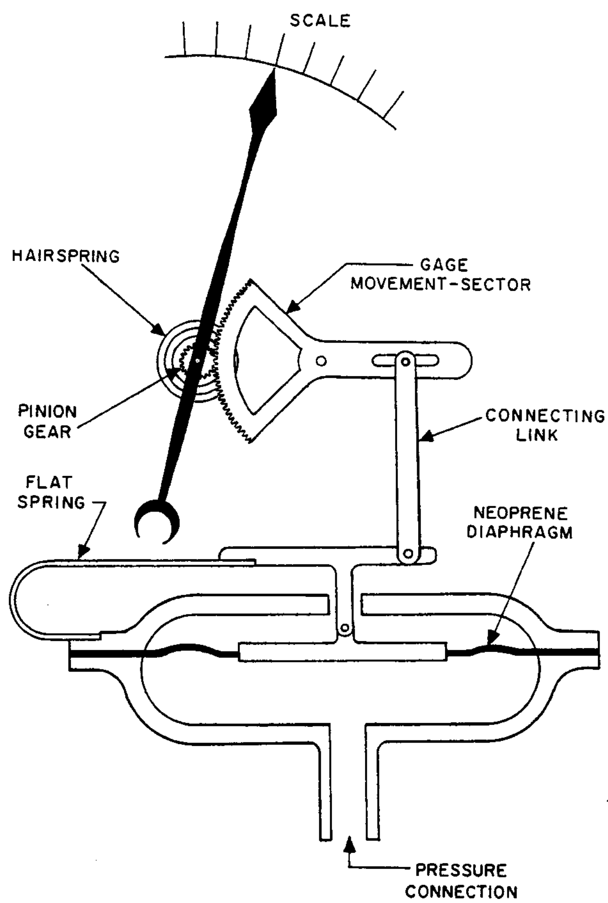
DIAPHRAGM ELASTIC ELEMENTS.—Diaphragm elastic elements are used for the measurement of relatively low pressures or

[12]Boiler control systems are discussed in chapter 11 of this text.

small pressure differences. Both metallic and nonmetallic diaphragms are in common use.

Metallic diaphragms are made from stainless steel, phosphor bronze, brass, or other metal. A metallic diaphragm element may consist of one or more capsules. Each capsule consists of two diaphragm shells (flat or corrugated circular disks) which are welded, brazed, or otherwise firmly fastened together to form the capsule. The capsules are all rigidly connected so that the application of pressure causes all capsules to deflect. The amount of deflection of a diaphragm gage depends upon the number of capsules, the design and the number of the corrugations, and other factors.

Nonmetallic diaphragms, also called slack or limp diaphragms, are made of leather, treated cloth, neoprene, or some other soft material. Nonmetallic diaphragms are spring-loaded. One common type of nonmetallic diaphragm pressure gage is shown in figure 7-27. When pressure is applied to the underside of the slack diaphragm, the diaphragm moves upward, although it is opposed by the action of the calibrating spring. As the spring moves, the linkage system causes the pointer to move to a higher reading. Thus the reading on the scale is proportional to the amount of pressure exerted on the diaphragm, even though the movement of the diaphragm is opposed by the calibrating spring.



38.212(147B)

Figure 7-27.—Nonmetallic diaphragm pressure gage.

PRESSURE GAGE INSTALLATION

Bourdon tube pressure gages used for steam service are always installed in such a way that the steam cannot actually enter the gage. This type of installation is necessary to protect the Bourdon type from very high temperatures. An exposed uninsulated coil is provided in the line leading to the gage, and the steam condenses into water in this exposed coil. Thus there is always a condensate seal between the gage and the steam line.

Pressure gage connections are normally made to the top of the pressure line or to the highest point on the machinery in which the pressure is to be measured. Pressure gages are usually mounted on flat-surfaced gage boards in such a way as to minimize vibration; this is a matter of considerable importance, since some ships experience very great structural vibration from screws and machinery. Efforts are currently being made to design gages capable of withstanding any vibration that may be expected from machinery. Pressure gages designed to withstand shock and vibration frequently use small size capillary tubing between the connections and the elastic elements to protect the gage mechanism and the pointer; small size tubing is used between the test connection or gage valve and the gage so that piping deflections will not cause errors in the gage readings.

MEASUREMENT OF FLUID FLOW

A great many devices, many of them quite ingenious, have been developed for the measurement of fluid flow. The discussion here is concerned primarily with the types of fluid flow measuring devices that find relatively wide application in shipboard engineering. These